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Field evaluation and spray deposition analysis of a battery-cum-manually operated boom sprayer on turmeric crop using water-sensitive paper

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Abstract
Uniform spray deposition across the crop canopy, and not merely the discharge and pressure delivered at the nozzle, ultimately determines whether a sprayer achieves effective pest and disease control. Following its laboratory characterisation, a battery-cum-manually operated boom sprayer, fitted with four flat-fan nozzles on a 2.0 m adjustable boom, was field-evaluated on a Pant Pitabh turmeric crop (vegetative stage, 240 mm height, 250 mm row spacing) at the Vegetable Research Centre, GBPUAT, Pantnagar. The sprayer was calibrated and operated at three forward speeds (1, 1.5 and 2 km/h) and spray deposition was assessed using water-sensitive paper (WSP) tags placed at the upper, middle and lower canopy positions of four plants per treatment; the exposed tags were scanned at 600 dpi and analysed with DepositScan software for volume median diameter (VMD), percentage coverage, image area, deposit density (no./cm²), deposition (µL/cm²) and droplet count. The theoretical field capacity of the machine ranged from 0.2 to 0.4 ha/h, the actual field capacity from 0.16 to 0.34 ha/h, and field efficiency from 80 to 85.5%. As travel speed increased from 1 to 2 km/h, percentage coverage rose from 56.8 to 60.8% at the upper canopy, 55.6 to 60.8% at the middle canopy, and 58.6 to 65.8% at the lower canopy, while deposition (µL/cm²) declined at all three positions, from about 93-100 µL/cm² at 1 km/h to 78-83 µL/cm² at 2 km/h, reflecting the shorter dwell time of the spray cloud over each plant at higher speeds. On the basis of the combined coverage, deposit density, deposition and droplet-count response, a travel speed of 1.5 km/h is identified as the optimum field operating speed of the developed sprayer for turmeric, balancing adequate canopy coverage against acceptable field capacity and deposition uniformity.

Keywords: Spray deposition, Water-sensitive paper, Deposit Scan, Boom sprayer, Turmeric and Volume median diameter

Introduction
The laboratory characterisation of a newly developed battery-cum-manually operated boom sprayer establishes the discharge and pressure that the machine can deliver at the nozzle, but effective pest and disease control depends on how that spray is actually deposited across the three-dimensional structure of the crop canopy. Spray droplets that are too small drift away without depositing on the target, while droplets that are too large fail to adhere to and spread across the leaf surface; the size, density and distribution of droplets reaching the upper, middle and lower parts of a plant therefore need to be quantified directly under field conditions rather than assumed from nozzle discharge alone.

Water-sensitive paper (WSP), a yellow, Bromophenol-Blue-coated card that turns dark blue on contact with aqueous spray droplets, is a well-established artificial collector for this purpose: exposed cards can be scanned and processed with image-analysis software to recover droplet size distribution, percentage area covered, deposit density and total deposition without requiring a tracer dye in the spray mixture. Coupled with a scanning-based deposition analysis tool such as Deposit Scan, this method allows canopy-position-specific deposition to be measured quickly across multiple plants and treatments, and has been used previously to evaluate spray delivery systems in row and orchard crops.

Building on the laboratory evaluation of the developed battery-cum-manually operated boom sprayer, the present study evaluates its field performance - field capacity and field efficiency - and its spray deposition characteristics on a standing turmeric crop, using water-sensitive paper tags placed at three canopy positions and three forward travel speeds, with the objective of identifying the field operating speed that gives the most uniform and adequate canopy deposition.

Materials and Methods
Field site, crop and machine parameters
The battery-cum-manually operated boom sprayer described in the companion laboratory study - a 2.0 m, four-nozzle flat-fan boom with adjustable height (260-900 mm), a 16 L tank, and a chain/sprocket-driven reciprocating piston pump operable in manual or battery mode - was calibrated prior to field testing and taken to the Vegetable Research Centre, GBPUAT, Pantnagar, for evaluation on a standing crop of turmeric (variety Pant Pitabh) at the vegetative growth stage(Fig.1). Boom height and nozzle spacing were set according to the measured crop height and row spacing (Table 1). Soil moisture content, bulk density and cone index (soil strength) at the test site were recorded before spraying (Table 2), and the theoretical field capacity, actual field capacity and field efficiency of the machine were determined from the boom width, forward speed and time lost in turning and refilling during the field runs (Table 3).

Fig 1: Field evaluation of manually operated boom sprayer

Table 1: Agronomical parameters of the turmeric crop at the field test site.

S. No.	Crop parameter	Value
1	Crop	Turmeric
2	Variety	Pant Pitabh
3	Height of crop	240 mm
4	Growth stage	Vegetative
5	Crop duration	250-270 days
6	Row-to-row spacing	250 mm

Table 2: Soil parameters recorded at the field test site.

S. No.	Soil parameter	Range / value
1	Moisture content of soil	13.63 %
2	Bulk density of soil	1.5-1.6 kg/cm3
3	Soil strength (cone index)	1.54 kg/cm2

Table 3: Field capacity and field efficiency of the developed boom sprayer.

S. No.	Machine parameter	Range
1	Theoretical field capacity	0.2-0.4 ha/h
2	Actual field capacity	0.16-0.34 ha/h
3	Field efficiency	80-85.5 %

Spray deposition assessment using water-sensitive paper

Spray deposition was evaluated on 1 September using water-sensitive paper tags fixed at the upper, middle and lower canopy positions of four sample plants for each of three forward travel speeds - 1, 1.5 and 2 km/h. After spraying, the tags were retrieved once dry, scanned at 600 dpi, and the scanned images were analysed using DepositScan software to obtain, for every tag, the volume median diameter (VMD, µm) (Fig. 2), percentage area covered, image area analysed (cm²), deposit density (number of deposits per cm²), volumetric deposition (µL/cm²) and the total number of droplets recorded.

Fig 2: Spray deposition by using water-sensitive paper

Results and Discussion

Field capacity and field efficiency

The agronomical, soil and machine parameters recorded at the test site are summarised in Tables 1 to 3. Crop height (240 mm) and row spacing (250 mm) were used to set the boom at an appropriate working height and the nozzle spacing along the boom, while the moderate soil moisture content (13.63%) and cone index (1.54 kg/cm²) indicated firm, trafficable field conditions suitable for the wheel-driven operation of the sprayer. The theoretical field capacity of 0.2-0.4 ha/h fell to an actual field capacity of 0.16-0.34 ha/h at a field efficiency of 80-85.5% (Table 3, Fig. 3), the shortfall being attributable to time lost in turning at row ends and in occasional tank refilling, consistent with field efficiencies typically reported for small boom sprayers of comparable width.

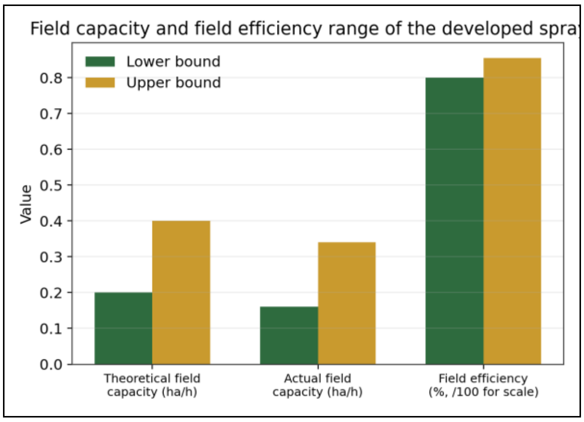

Fig 3: Teoretical field capacity, actual field capacity and field efficiency of the developed battery-cum-manually operated boom sprayer.

Spray deposition at 1 km/h travel speed

Table 4: Spray deposition parameters measured on turmeric crop at 1 km/h travel speed (water-sensitive paper analysis, DepositScan).

Plant / tag	Position	VMD (µm)	Coverage (%)	Image area (cm2)	Deposits/cm2	Deposition (µL/cm2)	Droplets
Plant 1	Upper	6802	32.25	28.97	109.7	29.03	3178
Plant 1	Middle	8443	34.30	44.03	27.03	42.25	1200
Plant 1	Lower	12012	73.27	46.26	36.50	131.66	1688
Plant 2	Upper	11209	52.41	53.28	53.80	85.45	2865
Plant 2	Middle	10698	61.04	41.26	60.10	95.63	2481
Plant 2	Lower	11445	48.23	61.34	56.00	72.75	3434
Plant 3	Upper	13821	80.90	57.07	10.80	166.75	615
Plant 3	Middle	13280	68.92	56.13	5.50	134.35	311
Plant 3	Lower	12862	57.00	66.50	43.20	105.11	2876
Plant 4	Upper	16795	61.75	65.29	44.80	89.85	2927
Plant 4	Middle	13336	57.97	73.59	38.40	109.02	2829
Plant 4	Lower	13370	55.90	71.14	81.00	90.07	5763

Spray deposition at 1.5 km/h travel speed

Table 5: Spray deposition parameters measured on turmeric crop at 1.5 km/h travel speed.

Plant / tag	Position	VMD (µm)	Coverage (%)	Image area (cm2)	Deposits/cm2	Deposition (µL/cm2)	Droplets
Plant 1	Upper	11053	48.88	53.36	54.60	76.84	2916
Plant 1	Middle	11190	53.08	55.62	44.40	89.64	2467
Plant 1	Lower	12732	66.54	50.64	17.80	119.65	900
Plant 2	Upper	12465	46.19	62.11	21.60	76.66	1340
Plant 2	Middle	10442	49.49	52.46	58.50	77.20	3068
Plant 2	Lower	11963	56.90	61.32	34.00	104.23	2084
Plant 3	Upper	14019	62.02	63.72	40.40	108.85	2572
Plant 3	Middle	12573	60.10	61.30	48.30	108.80	2961
Plant 3	Lower	10098	45.29	44.45	23.30	60.33	1034
Plant 4	Upper	11129	61.21	46.04	42.70	103.05	1968
Plant 4	Middle	12512	67.46	44.29	25.20	109.26	1115
Plant 4	Lower	11796	47.92	48.05	54.20	47.05	2602

Spray deposition at 2 km/h travel speed

Table 6: Spray deposition parameters measured on turmeric crop at 2 km/h travel speed.

Plant / tag	Position	VMD (µm)	Coverage (%)	Image area (cm2)	Deposits/cm2	Deposition (µL/cm2)	Droplets
Plant 1	Upper	13571	63.57	47.94	54.30	73.43	2605
Plant 1	Middle	12700	56.52	50.79	11.70	94.06	595
Plant 1	Lower	9812	59.44	40.14	23.40	62.35	939
Plant 2	Upper	12946	66.06	54.27	25.60	87.62	1389
Plant 2	Middle	12405	65.70	54.14	43.60	121.73	2358
Plant 2	Lower	11306	66.22	54.12	25.60	70.84	1385
Plant 3	Upper	12178	42.47	56.16	146.50	41.50	8230
Plant 3	Middle	11826	64.47	56.56	28.30	71.50	1602
Plant 3	Lower	12618	58.51	53.06	42.60	51.74	2262
Plant 4	Upper	13112	70.99	47.86	45.30	111.71	2169
Plant 4	Middle	9587	56.62	52.87	33.60	43.92	1777
Plant 4	Lower	13861	79.19	55.50	21.00	143.37	1168

Effect of travel speed and canopy position on deposition parameters

Spray deposition parameters recorded from the water-sensitive paper tags at the upper, middle and lower canopy positions, at travel speeds of 1, 1.5 and 2 km/h, are summarised in Tables 4 to 6 (mean of four sample plants) and illustrated in Figures 4 to 8.

Percentage coverage increased with travel speed at all three canopy positions (Fig. 4): from 56.8 to 60.8% at the upper canopy, 55.6 to 60.8% at the middle canopy, and most markedly from 58.6 to 65.8% at the lower canopy as speed rose from 1 to 2 km/h. This pattern is consistent with the higher piston cycling rate and correspondingly higher discharge and pressure generated at 2 km/h (established in the companion laboratory study), which produces a finer, more widely dispersed droplet spectrum and hence greater area coverage on the water-sensitive paper, even though the total volume of liquid delivered to a given point of canopy for a shorter dwell time is lower.

Volume median diameter (VMD) showed a comparatively modest and position-dependent response to speed (Fig. 5), remaining broadly in the range of 11,400-13,000 µm across all combinations, with the upper canopy position recording the highest VMD (about 12,950 µm) at 2 km/h. Because VMD reflects nozzle atomisation characteristics more than canopy position, its relative stability across speeds indicates that nozzle performance itself was not materially altered by the range of speeds tested, and that the coverage and deposition differences described below arise mainly from spray dwell time and canopy penetration rather than from changes in droplet size at the nozzle.

Deposit density (number of deposits per cm²) and total droplet count both varied non-monotonically with speed and canopy position (Fig. 6 and 7): at the upper canopy, both deposit density and droplet count increased with speed (from about 54.8 to 67.9 deposits/cm² and 2396 to 3598 droplets as speed rose from 1 to 2 km/h), whereas at the middle and lower positions they generally declined at the higher speed. This contrast suggests that at higher travel speed the more energetic, finer spray cloud tends to deposit preferentially on the more exposed upper canopy, while the lower and middle leaves - partially shielded by the canopy above them - receive proportionally fewer droplets as the shorter dwell time reduces penetration into the lower strata.

Volumetric deposition (µL/cm²) declined consistently with increasing speed at all three canopy positions (Fig. 8): from 92.8 to 78.6 µL/cm² at the upper canopy, from 96.2 to 82.2 µL/cm² at the middle canopy, and from 99.9 to 82.1 µL/cm² at the lower canopy as speed increased from 1 to 2 km/h. This decline mirrors the shorter residence time of the boom over each plant at higher forward speed, which reduces the cumulative volume of spray reaching the leaf surface even though instantaneous discharge and pressure at the nozzle are higher; it is the direct field-scale counterpart of the discharge-pressure trends established under static laboratory conditions in the companion study.

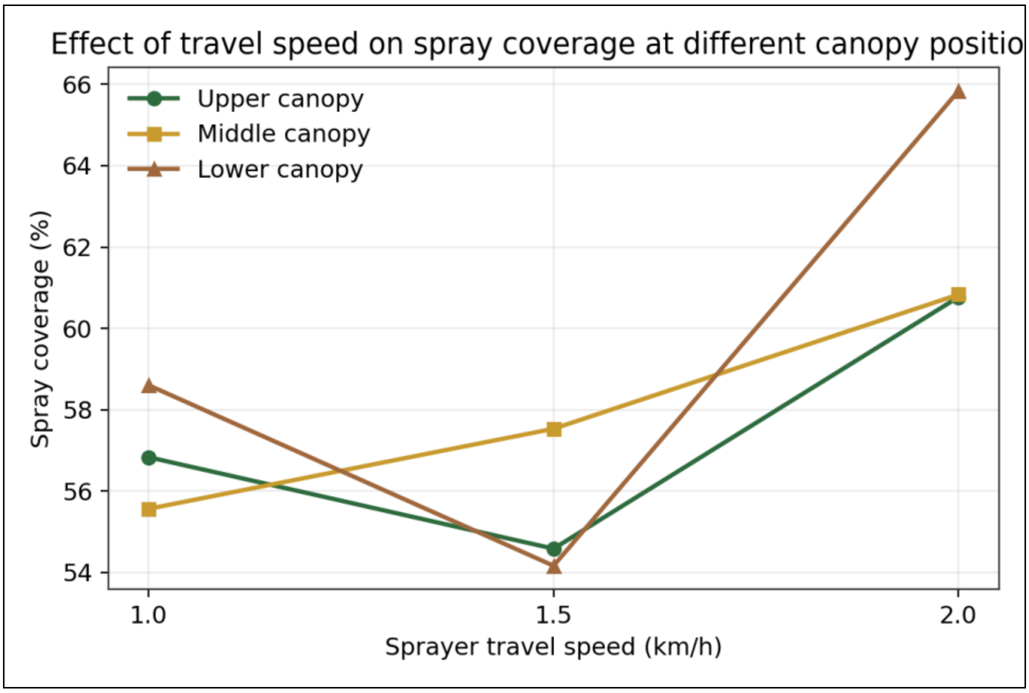

Fig 4: Effect of travel speed on spray coverage (%) at upper, middle and lower canopy positions.

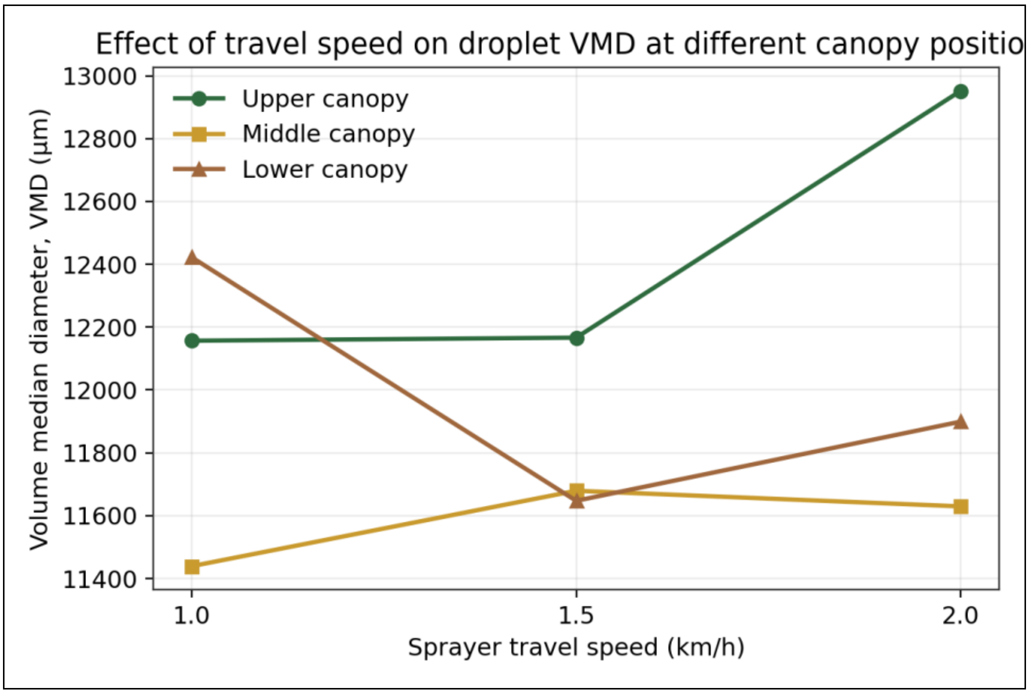

Fig 5: Effect of travel speed on droplet volume median diameter (VMD) at different canopy positions.

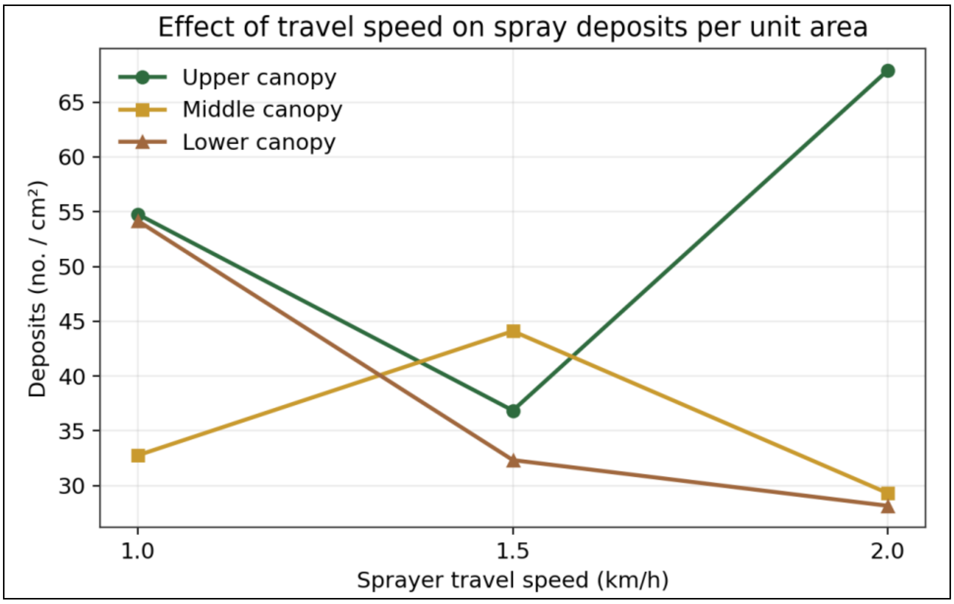

Fig 6: Effect of travel speed on spray deposit density (no./cm²) at different canopy positions.

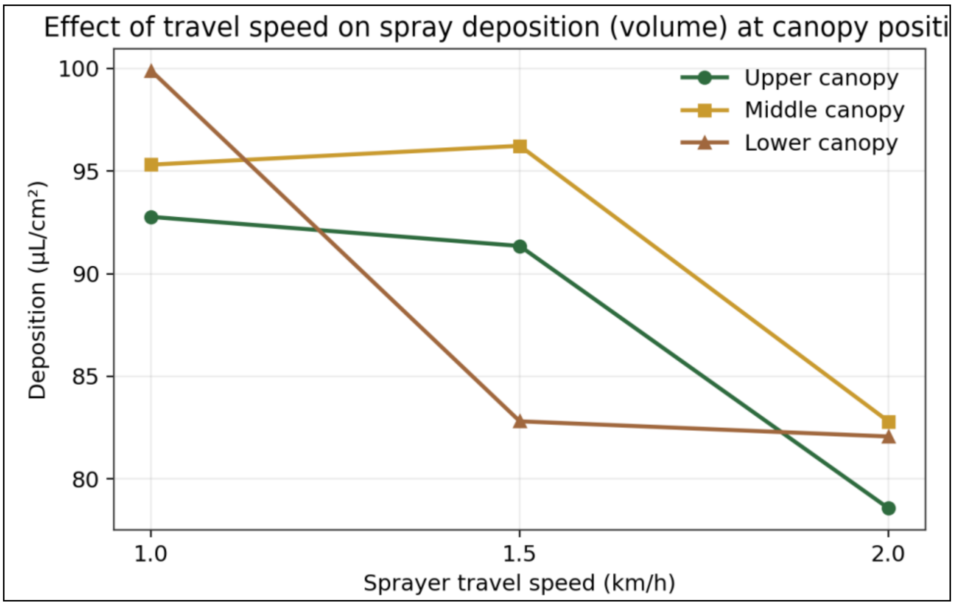

Fig 7: Effect of travel speed on volumetric spray deposition (µL/cm²) at different canopy positions.

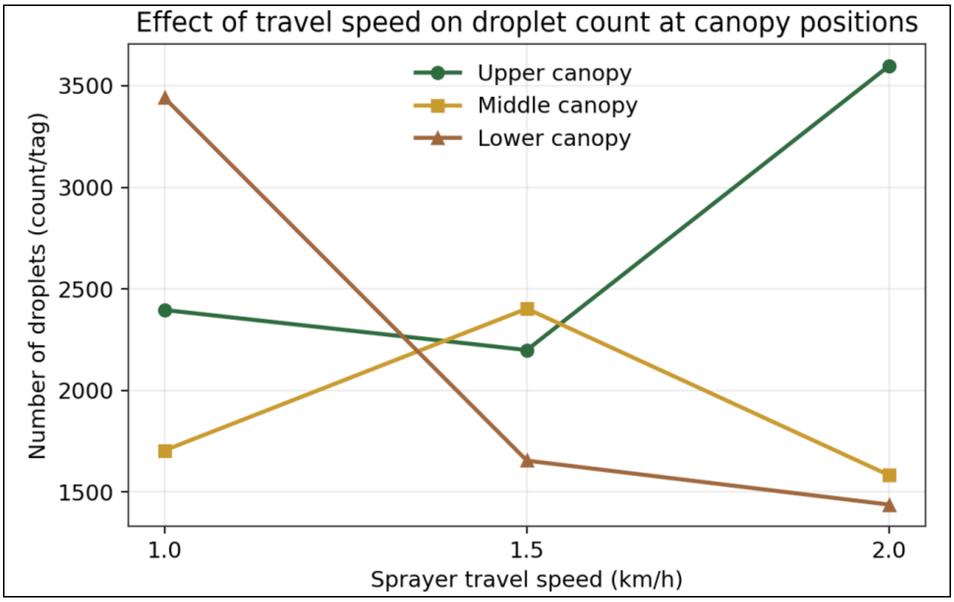

Fig 8: Effect of travel speed on droplet count at different canopy positions.

Conclusion

Field evaluation of the developed battery-cum-manually operated boom sprayer on a standing turmeric crop showed an actual field capacity of 0.16-0.34 ha/h at a field efficiency of 80-85.5%, confirming that the boom configuration substantially raises area coverage per unit time relative to a single-lance knapsack sprayer. Analysis of water-sensitive paper tags at the upper, middle and lower canopy positions across three travel speeds showed that percentage spray coverage increased with travel speed at all canopy positions, while volumetric deposition (μL/cm²) declined consistently with speed at all positions, reflecting the shorter spray dwell time per plant at higher speeds; deposit density and droplet count responded differently by canopy position, increasing with speed at the upper canopy but generally decreasing at the middle and lower canopy.

Considered jointly, these results indicate that operating the developed sprayer at 1.5 km/h in the field provides the most favourable balance between area coverage, field capacity and canopy deposition uniformity across the plant profile, and this speed - together with the full-stroke, 1-1.5 km/h operating envelope established in the companion laboratory study - is recommended for practical deployment of the sprayer on row crops such as turmeric. Together, the laboratory and field evaluations demonstrate that the battery-cum-manually operated boom sprayer offers small and marginal farmers a low-cost, low-drudgery alternative to the conventional knapsack sprayer, combining wider swath coverage, controllable discharge and pressure, and adequate, if position-dependent, canopy deposition.

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